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ABSTRACT

This paper examines the special challenges that English-as-a-Second-Language (ESL) students face in succeeding in science classrooms in U.S. schools. Particular focus is on how students in one experimental classroom (a Grade 2 and Grade 3 two-way bilingual English-Spanish class in a small western city) learned to apprehend scientific meaning with their peers, their teachers, and the researchers through the collaborative construction of a language of instruction for successful science learning. This was done in the context of student-generated computer models. Through active participation in the construction and use of this language of instruction, students made significant strides in acquiring ways of thinking, acting, and talking that should lead to their continued success in science. Student-generated computer models, in conjunction with the construction of physical models and other hands-on activities, can provide an effective strategy for mediating the difficulties that English language learners often have with mastering the academic discourse of science. The project goals were to help students to provide better explanations of natural phenomena, to teach them to view science as process of inquiry rather than a body of facts, to encourage students to pursue their own understandings of scientific concepts as well as learn traditional academic concepts, and to explore the effects of modeling on the participation and success of both girls and language minorities. (Contains 37 references.) (KFT)

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# The Emergence of a Language of Instruction for Successful Model-Based Elementary Science Learning: Lessons from a Bilingual Classroom

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# The Emergence of a Language of Instruction for Successful Model-Based Elementary Science Learning: Lessons from a Bilingual Classroom

**Cory A. Buxton, School of Education, University of Colorado, Boulder**

## Introduction

Science is viewed by many as utilizing a language and functioning within a culture that is unique and distinct from other ways of knowing, acting and talking. Furthermore, the language and culture of science are often conceptualized and enacted in opposition to the language and culture of everyday life – i.e. objective vs. subjective and value-free vs. value-laden (Lemke, 1990; Longino, 1990). Despite the ample arguments that this distinction is untrue in practice (Harding, 1991; Kleinman, 1998; Kohlstedt & Longino, 1997; Longino, 1989), in order for students to succeed in the science classroom, they must become comfortable functioning within this culture of school science.

Getting students to think and act more like scientists has been one of the goals of research on how to best use computer technology as a took for science learning. It has been argued that the rapid spread of the microcomputer to school settings provides opportunities for approaching science learning in new ways, what Salomon, Perkins, & Globerson (1991) have referred to as students and computers acting as "partners in cognition." Certain uses of personal computers have been shown to aid students' construction of science concepts as well as their general problem solving abilities (Frederiksen & White, 1998; Hawkins & Pea, 1987; Krajcik & Layman, 1993; Linn, 1992). Conceptually, these researchers have tended to rely upon a cognitive change perspective of leaning and have focused on how computer models can be used to expose and correct students' scientific misconceptions.

Little research has been done, however, that examines how the development and use of student-generated computer models can serve to facilitate students' development of the ability to "talk science" (Lemke, 1990; Rosebery, Warren, & Conant, 1992). Training in the discourse of school science cannot be overlooked because its mastery is essential if students are to socially construct an understanding of science concepts that is compatible with the accepted school science knowledge base.

Mastery of the discourse of school science is especially important for the English Language Learners in our schools. It has been repeatedly shown that these students face additional barriers to success in school science (Buxton, 1998; Chamot & O'Mailey, 1986; Fathman, Quinn, & Kessler, 1992; Lee & Fradd, 1998; Mason & Barba, 1992; Rosenthal, 1996). In part this can be attributed to the fact that many of these students, especially those from disadvantaged socioeconomic backgrounds, have had less experience with both science and technology than their mainstream American peers. Another significant factor, however, is that the cultural and linguistic backgrounds that many of these students bring with them stress methods of argument, proof and understanding of the natural world that are significantly different than the logico-deductive Western epistemology that has given rise to modern science. In order for

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students from such backgrounds to succeed in school science, they must first learn to think and talk in this Western academic language. Acquiring the academic language proficiency needed to talk science takes years of practice, even under the best of circumstances (Cummins, 1979). Under the conditions faced by many English Language Learners, such academic language development is next to impossible (Carrasquillo & Rodriguez, 1996; D'Amato & Tharp, 1997; Guberman, 1997; Lynch, 1993; Richard-Amato, 1996; Sutman, Allen, & Shoemaker, 1986).

The Science Theater/Teatro de Ciencias (sTc) project at the University of Colorado, Boulder (a 3-year, NSF-funded technology enhancement grant) had several objectives based on the use of student-designed computer models as a means for representing and explaining science concepts. These objectives included:

1. Helping students to provide better explanations of natural phenomena;
2. Helping students to view science as a process of inquiry rather than as a body of facts;
3. Encouraging students to pursue their own, everyday understandings and beliefs about scientific concepts, as well as the traditional academic understandings; and
4. Exploring the role that modeling has on both the participation and success of girls and culturally and linguistically diverse students in the study of science.

The focus of this article is on how the students in one experimental classroom (a 2nd/3rd grade two-way bilingual [English-Spanish] classroom in a small western city) learned to negotiate scientific meaning with their peers, their teachers and the researchers through the collaborative construction of a language of instruction for successful science learning. This was done in the context of student-generated computer models. Through active participation in the construction and use of this language of instruction, students made significant strides in acquiring ways of thinking, acting and talking that should lead to their continued success in school science. My basic thesis is that the use of student-generated computer models, in conjunction with the construction of physical models and other hands-on activities can provide an effective strategy for mediating the difficulties that English Language Learners often have with mastering the academic discourse of science.

## Learning to Talk Science

In considering how learning to talk about science becomes a major factor in students' success in school science, I rely on the work of both Lemke (1990) and Lee and Fradd (1998). Lemke has claimed that,

> The language of classroom science sets up a pervasive and false opposition between a world of objective, authoritative, impersonal, humorless scientific fact and an ordinary, personal world of human uncertainties, judgments, values and interests. It is the second world in which we all feel comfortably (and uncomfortably) at home, and science, like all other human endeavor, is a part of that world. It is not something that lies outside it or should be set in opposition to it, but many of the unwritten rules about how we are supposed to talk science make it seem that way (p. 130).

Following Lemke's logic, it is largely due to the discourse of science, with its foreign and

objectifying language, that so many people feel alienated from science practice. However, this also implies that if more attention was paid to explicitly teaching this discourse of science then individuals would be less likely to feel alienated by and unfit for *doing* science. Just as in learning a second language, fluency in talking science requires practice in speaking, not just in listening. If we conceptualize science as an additional culture, language and literacy that must be successfully articulated onto one's home culture, native language and other academic literacies, then we can discuss this question of learning to talk, act and do science from the perspective of multicultural/multilingual competence. Lemke follows this line of reasoning when he claims that,

> Although we often equate the ability to talk science with having a knowledge of science, we don't teach students how to talk science in the science classroom – we expect them to catch on and learn it on their own (p.22).

Another way to think about the importance of learning to talk science can be taken from the work of Lee and Fradd (1998). They have developed a conceptual framework for what they refer to as *Instructional Congruence*, by which they mean, "the process of mediating the nature of academic content with students' language and cultural experiences to make such content accessible, meaningful, and relevant for diverse students" (p. 12). They argue that many attempts to teach science to English Language Learners have focused on creating *cultural* congruence, where the teacher tries to match the content and processes of what is to be learned to the language and culture of the students (D'Amato & Tharp, 1997; Dalton & Tharp, 1997; Moll, Amanti, Neff, & Gonzalez, 1992; Tharp & Dalton, 1994). While attention to cultural congruence may be a positive step in making learning relevant to students, it is insufficient for adequate science learning. The teacher must move beyond cultural congruence to include an understanding of the nature of science, the scientific worldview, and the ability to both do and talk about science. This leads Lee and Fradd to their model of instructional congruence that attempts to incorporate both cultural congruence and a focus on scientific knowledge and habits of mind.

One of the pieces of the resulting instructional congruence model is an emphasis on facilitating students' opportunities to talk science. Lee and Fradd follow Lemke in advocating practice in talking science as essential for developing the scientific discourse patterns that are generally considered an indication of "knowing" science. They claim that science talk can focus on written, pictorial, graphic or electronic formats. Lee and Fradd go on to argue that the development of scientific reasoning "can be facilitated using formats that do not require an explicit knowledge of verbal language" (p. 17), and that hands-on activities are a way to provide this kind of opportunity. Lee and Fradd conclude by calling for further research in bilingual classrooms with teachers and students of two different linguistic and cultural backgrounds with the goal of providing insights into how successful classrooms establish instructional congruence in science learning and language development. This study provides such an example.

Finally, in discussing the importance of learning to talk the language of science, I should note that the recent National Science Education Standards (National Research Council,

1996), unlike prior documents outlining how students should go about learning science, do refer to the importance of students learning to communicate their understanding of science to others. The document claims that teachers can provide opportunities for this communication if they, "structure and facilitate ongoing formal and informal discussion based on a shared understanding of the rules of scientific discourse" (p. 50). However, the document does not elaborate upon what the authors see as these rules of scientific discourse or upon how teachers are to create a shared understanding of these rules with their students. It seems as if it is up to students (and teachers) to infer these rules for themselves. I believe that the process by which students go about learning to create computer-based models provides a context for generating and clarifying some of these rules of scientific discourse.

## Computer Modeling and Science Learning

The role of instructional technology, and more specifically, the role of computers as tools for enhancing science learning, has been a topic of a great deal of study since the rise of the microcomputer in the 1980's. As Marcia Linn argued over a decade ago (Linn, 1987),

> The potential of technology for science education remains largely unknown while offering tremendous promise. Just as the ramifications of the steam engine took generations to be realized, so too we can expect the impact of technology on science education will require extensive exploration, investigation and refinement before it is well understood.... Clearly, using technology to implement existing models for instruction such as books or lectures fails to tap the resource. In contrast, using technology for exploration of microworlds, real time data collection or simulated decision making may well yield some unanticipated consequences. (p. 290)

This quote is just as applicable today as it was in 1987. While we have leaned a great deal about computers as tools for science teaching and learning, there is still much more to be discovered. More recently Linn (1992) has explored three effective uses for computers in classroom settings: 1) using computers to collect and display data that students can then interpret; 2) using computers to communicate and synthesize information from a number of sources situated across space and time; and 3) using computers to help students predict and test natural phenomena by asking members to make predictions, agree or disagree with the group consensus, and then test those predictions using computer models. Unfortunately, computers are seldom used in these ways in elementary school science.

Much of the innovative research that has been done on uses of computers in the science classroom falls into Linn's first category, using computers to collect and display data for students to interpret. This type of project has come to be known as Microcomputer-Based Laboratories (MBL's). Conceptually, the goal of MBL's has been an emphasis on teaching students problem solving and critical thinking, especially through the use of reading and interpreting graphs, which are the usual output generated by MBL's (Linn, Layman, & Nachmias, 1987; Mokros & Tinker, 1987; Reif, 1987; Rivers & Vockell, 1987). These studies have largely been done at the secondary school level.

White and Frederiksen have developed programs within Linn's third category of effective computer use, getting students to make predictions about natural phenomena and then testing those predictions using computer models (Frederiksen & White, 1998; White & Frederiksen, 1990). They have explored model-based problem solving in both secondary and post-secondary educational settings, focusing on how students develop what they refer to as Intermediate Causal Models (ICM's) and how these models can then be used as problem solving tools. White and Frederiksen claim that the are four instructional ramifications for their work with ICM's. They are to: 1) use semi-abstract representations and causal reasoning in modeling physical systems; 2) teach modeling, not just models; 3) teach problem solving as model-based reasoning; and 4) recognize the critical importance of metacognition.

As can be seen from the examples presented in this section, most of the work done to date using computers as tools to aid students' science learning has been decidedly cognitive in nature. These studies have focused on identifying and ameliorating students' misconceptions, and developing their abilities in problem solving and critical thinking, as well as creating a better understanding of the processes used in the practice of science. This work was been done almost exclusively in secondary school settings. In contrast, little has been done that focuses on the social construction of scientific understanding or how the creation and use of student-generated computer models can serve as a tool for developing students' competence in the discourse of science that is necessary for such social construction to take place. Thus, the sTc project expands on the prior work done in this area in two ways: 1) by pushing the question of appropriate use of computers for science learning down to the primary elementary grades; and 2) by focusing on the role of the discourse of school science as a necessary condition for students to prove mastery of science concepts.

## The Setting

The sTc project took place at Front Range Elementary, a mid-sized elementary school in a small western city. The school district has an open enrollment policy meaning that any student can attend any school, a policy that has given rise to a number of focus programs. Front Range Elementary is one of two elementary schools in the district offering a two-way bilingual program. In this model of bilingual education, classes are composed of roughly half-native English speakers and half-native Spanish speakers. Instruction alternates by day, so that on one day all instruction (including science) is in English, and the next day, all instruction (again including science) is in Spanish. The combined second and third grade class where this study took place was composed of 26 students, 18 of whom were native Spanish speakers and 8 of whom were native English speakers. The classroom teacher, Teresa Garcia, was a veteran teacher, with 20 years experience working in bilingual programs and 14 years at Front Range Elementary. A bilingual classroom aide, Flora Gutierrez, was also present in the classroom for most of the day.

## Data Collection

The data for this particular study were collected during the 1997-98 academic year. During the year the class worked on four science units, each about eight weeks in length. The school followed the practice of picking a school-wide science theme each year, which for the year in question was "environments and ecosystems." This theme served as a constraint upon the topics that we taught during the year. The first unit we developed focused on seed dispersal mechanisms, which we also used as an introduction to modeling and to the computer software. The second unit was pollination, the third was food webs and the fourth unit was recycling. The project researchers collected ethnographic field notes during twice weekly classroom sessions. During these sessions we functioned as participant observers, engaged at various times in teaching the entire class, working with small groups, working with individual students in the classroom and the computer lab, or stepping back to observe as Teresa lead the class.

Additional data came from the collection of classroom artifacts such as copies of student-produced computer models, stories and drawings, as well as books, handouts and other instructional materials used in the class. Finally, individual interviews were conducted with the students at two points during the year (at the end of the Science Museum and at the end of the recycling unit), and periodically, with the classroom teacher, Teresa.

## Data Analysis

The Constant Comparative Method, originally developed by Glaser and Strauss (1967), was used to derive a grounded theory. According to Strauss & Corbin (1990),

> A grounded theory is one that is inductively derived from the study of the phenomenon it represents. That is, it is discovered, developed and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis and theory stand in reciprocal relationship with each other. (p.23)

In other words, instead of beginning with theory and trying to prove it, the researcher begins with an area of study and then allows what is relevant to that area of study to emerge in the course of the research and analysis. This approach to data analysis was particularly appropriate for this study for two reasons. First, since most of the prior studies of computer models in science education have been informed by perspectives from cognitive psychology, the sociological perspective that informs grounded theory provides a fresh lens with which to look at the issue of student model building. Second, since this study's emphasis is on exploring how students learn to adapt and appropriate the discourse of school science, I rely on a number of ideas from sociolinguistics that fit well with the sociological paradigm that underlies the grounded theory perspective.

## Findings

Analysis of the data yielded patterns of behavior that illuminate a grounded theory that I refer to as a *language of instruction for successful model-based elementary science learning*. This language of instruction developed out of a melange of circumstances and contextual features, including: 1) the experiences of the classroom teacher working with bilingual/bicultural grade school children; 2) the experiences of the researchers teaching science and computer skills to young children; 3) the demands of teaching modeling (both computer-based and physical) to children of this age group; and 4) perhaps most importantly, from watching this group of students interact, and taking their lead in terms of how they designed successful learning experiences for themselves. While I do not claim that the language of instruction we constructed is the only way to teach science through model building to elementary school students, the lessons we learned in this setting have lead us to a develop a set of beliefs and understandings that I suspect are largely transferable to any setting where models are used to teach science to young children. I believe this approach is especially effective with English Language Learners in the elementary grades.

Following Strauss & Corbin (1990) I came to explore our concept of the language of instruction in terms of a sociological paradigm with five components: 1) causal conditions that lead to the phenomenon; 2) properties of the phenomenon; 3) the contexts in which the phenomenon occurs; 4) actions taken in response to this phenomenon; and 5) consequences of those actions. An exploration of the dynamic interplay among these five constructs will lead me, in the following sections, to elucidate the primary characteristics of the language of instruction for successful model-based elementary science learning that we developed in this setting. In the last section, I will tie these findings back to my conceptual framework, and discuss the implications of this language of instruction for use in other settings.

## Causal Conditions for Successful Use of the Language of Instruction

One of the keys to being able to use models successfully as tools for science learning is for students to gain an understanding of the value of models, and what a given model is able to (and not able to) show. This understanding is intimately linked to understanding how to talk about models in meaningful ways. By talking about models in meaningful ways, I mean focusing the talk on those aspects of the model that are relevant for science learning. This is a skill that has to be taught explicitly, as children are likely to focus on aspects of the model that are extraneous to the science concepts.

While we began the project talking about a number of possible valid uses for models, students gravitated towards the image of models as props or tools that are used to tell a story. While this was somewhat different that our initial goal of using models to explore causal mechanisms, "models as storytelling devices," similar to an animated storybook, became a metaphor the students adopted. This metaphor, in turn, helped students learn to

view science as a discourse, and also increased their willingness to engage in content-related discussions, both with their peers and with adults. This reasoning is shown in the following fieldnote excerpt,

> Groups were working on questions about various aspects of model-building. Group four answered the question about whether or not details are important in a model. They said yes and no, that some details are more important and some are less important. I asked how they determined which was which. They claimed that the more important ones are those that are related most directly to the story that you are trying to tell with your model. Those that aren't relevant to your story are less important (field notes 1/27)

Other causal conditions for successful use of the language of instruction tended to cluster around the idea of increasing students' comfort level, both in their interactions with computers and in their discourse about science. One aspect of increasing students' comfort level with computer modeling has to do with choosing computer software with which students can be successful. Computer modeling is a complex task, and in order for students to be able to focus on what they are modeling and not just how to get the model to work, the right software is needed. In our third and final year, we switched the software we used from Cocoa (Cypher & Smith, 1998), a simulation design program, to the Amazing Animation program (Cornish, 1994), designed to create animations rather than simulations. Animations emphasize spatial and temporal relationships rather than cause and effect mechanisms. With this change in software, we saw a dramatic difference in how students interacted with and made use of their models (which we came to refer to as movies due to their animated-story nature). In the following excerpt, Teresa, the classroom teacher, discusses her feelings about switching software.

> Now I feel very happy, and my Hispanic students, the bilingual students, are doing good work. Take Belle, she did a beautiful model on the computer and she's a second grader. I know that my kids have the brains, have everything that they need to be successful for their grade level, it was just that the [Cocoa] program was too hard. Now [with Amazing Animation] the computer actually did what they expected it to do. They love to make the backgrounds and stamps, and a lot of them would do that all day if they could. I really see the kids learning a lot about the topics we study, and I'm not sure I would say that about Cocoa. (Teresa interview 3/2)

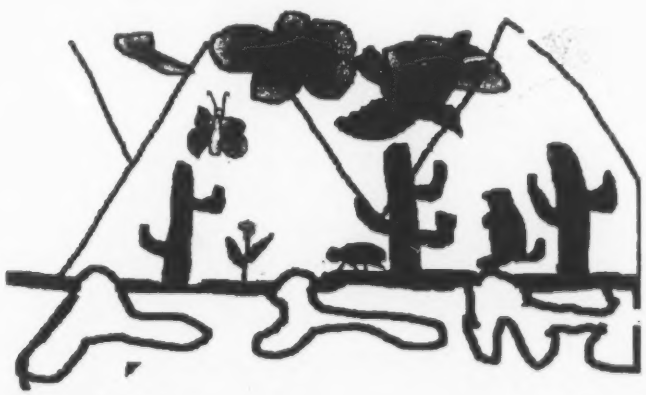

**Figure 1 - Belle's food web model**

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Another way of increasing students' comfort with talking about science was to begin with experiences that were familiar to students and then gradually expand beyond their experiences. Two concrete manifestations of this strategy were to begin our studies with a focus on the local environment, and to give students the freedom to use either their first or second language in describing and talking about their models. The following excerpt provides an example of the first of these strategies.

> Teresa is telling a personal story about how she has a large backyard and a cat that likes to chase and kill mice but doesn't ever eat the mice. Teresa wonders aloud what happens to the mice because she rarely sees the dead mice lying around in her yard. One student says that the mice rot. Another says that they decompose. Teresa asks: "So do you think that decomposition is Mother Earth's way of getting rid of the garbage? The earth makes garbage too, dead animals, dead plants, dead leaves. Do you think that if Erika and I go to Africa that we will see piles of dead elephants? (class responds: No!) Then where do the dead elephants go? That is where decomposition comes in. But what about things that don't decompose?" Teresa shows students a picture of a goose with an O-ring around its neck and asks them in groups to try to figure out what is happening in the picture. After several students comment about the picture she reads the caption that accompanies it and discusses how this is a local problem because these geese live right here in Colorado: "This doesn't happen in Africa or at the North Pole – this is happening right here in Colorado." (field notes 3/11)

In summary, the causal conditions that we found to be necessary for students to begin to engage in the discourse of science in this context were an understanding of the purpose of models and the development of a classroom environment where students became comfortable exploring what it means to think, do and talk about science. Factors that lead to an adequate student comfort level included selecting the appropriate computer software and starting with topics that students could relate to based on their prior experiences.

## Properties of the Language of Instruction

The language of instruction that we developed for teaching science in this setting evolved out of the causal conditions described above. While we were not able to enumerate these causal conditions from the outset of the project, by paying close attention to when students were able to succeed in the modeling tasks and when they struggled, we gradually became aware of the causal conditions, and modified our tasks and strategies accordingly. So, for example, one of the properties of our instruction that developed over time was an increased reliance on students' literacy and drawing skills in the classroom. The project was originally designed to circumvent the need for student literacy due to the pictorial nature of the computer modeling programs. However, we found that activities done in the classroom prior to students starting to work on the computers (what we came to refer to as pre-modeling activities) were essential for guiding students' work when they began to make their models. These pre-modeling activities were predominantly literacy-based. However, since the range of literacy skills in the class was quite large, we found that some students were more successful drawing pictures of what they planned to show in their model rather than writing out a narrative. The following excerpt demonstrates this approach:

> Teresa: It's up to you whether to draw pictures or write your story, but you have to do one or the other before you can go to the computers. I heard Rebecca say that she preferred to write the story and then maybe draw the pictures, and Bobbie said he'd rather draw the pictures. Either one is OK. What is important is that you have to put into practice everything that you have learned so far about making movies. You have to prepare yourselves really well before you go to the computers so that you know what to do when you go upstairs. You can do it however you want as long as you have a plan for what you are going to do and you teach something interesting with your model.
> (field notes 3/17)

Another property of the language of instruction that we developed was an emphasis on the scientific processes of design, experimentation, and revision. These three characteristics can be seen as parallel to the three stages of modeling that we addressed: pre-modeling, modeling and post-modeling. All three of these aspects are important for the successful construction of models. We developed several activities in the classroom that made use of all three steps using physical models rather than computer models in order to teach these processes. The following is an example of such a physical modeling activity:

> Teresa is leading a group activity unwrapping several commercial boxes of chocolates and looking at all the excessive wrapping layers of the products. She asks: "What do you see? What are the similarities and what are the differences of the products?" After a discussion of the wasteful nature of this packaging, students are given the task in groups of designing a chocolate box that is still attractive but is less wasteful. Students need to plan their box design, construct the box, and then share and discuss their box with the rest of the class. I spend most of the time with a group composed on Julia, Josue, Delilah, Mario and Amy (4 native Spanish speakers and 1 native English speaker) The discussion is revolving around how to decorate their box. At this point all conversation is in Spanish. This activity has aspects of design, creation and revision as the group works on the box. Ideas are discussed, such as how to best use the least amount of paper to cover all the parts of the box (an example of design). The box is being assembled by group effort (model creation) and revision happens when there is dissatisfaction with the result. For example, when Josue wrapped the box, Julia was dissatisfied with the gaps that were left, and unwrapped it to try it again. (field notes 3/10)

Another key property of the evolving language of instruction had to do with providing the optimum amount of student choice in how to proceed. As researchers we began the project with the view that allowing a great degree of student choice and direction would lead to student ownership of the models and a better final product. Over time we found, however, that with students this young and a project so complex, students could quickly become overwhelmed by the complexity, and lose all sense of what to do. We gradually began to provide more structure in the form of the pre-modeling activities. These activities were meant to decrease the confusion that is described in the following excerpt.

> Fatima was slow to start, and needed a lot of one-on-one help from Carlos in order to finish her stamps by the end of the period. She seemed upset with her drawing and spent a long time saying that she was unable to think of anything to make. She could describe parts of the story that she wanted to tell, but couldn't decide what order to put the events in or what should be in the background and what needed to be stamps because they needed to move. She told her story orally several times, but by the end of the period had very little actually accomplished on the computer. (field notes 3/3)

In summary, the properties of our language of science instruction that developed over the course of the project can be thought of in terms of finding the proper balance along several dimensions. The first dimension is the balance between students' written expression, their oral expression and their computer models. While we started the project with the hope that the computer models themselves would be the medium of communication by which students would be able to express their conceptual understanding of science, we found that other modes of communication needed to be accessed before students could make successful models. Thus, we needed to balance the amount of pre-modeling that we required with the opportunities students had to create their models. Put another way, we tried to balance model design, model creation and model revision. The other major dimension of balance was between student choice and adult direction. While we began the project giving students the maximum amount of choice, over time we began to provide more direction and guidance.

## Context in Which the Language of Instruction Occurs

In practice, the language of instruction that we developed differed in significant ways between the two principle settings of the project, the classroom and the computer lab. However, in both settings we gradually came to realize that we, as teachers and researchers, were not wholly, responsible for it's development and usage. Discourse among students, both in the classroom and when at the computer, played a significant role in how students made sense of their models, the science being represented therein, and how to talk about these things. One common way that this language development occurred was through students talking about their own and each other's models as they made them. An example can be seen in the following passage:

> Jesus, Belle, Barbara and Stuart are talking as they work. Delilah, who is over on computer #6 which faces the other direction had less interaction with the rest of the group, and was more likely to ask her questions of me rather than one of her peers (all conversation was in English) --
> Belle (to Jesus): Look how ugly yours is!
> Jesus: I'm going to erase mine. Now what color? (tries a shade of green) No, not that color.
> Barbara: Where is brown?
> Stuart: Right there (indicates brown on the color pallet).
> Jesus, Belle, Barbara and Delilah are all drawing prairie dog towns; Stuart is drawing a single tree very carefully.
> Belle (to Barbara): How are you doing it? (looks at her screen) Oh, you're doing it smaller than me.
> Barbara: First, I've got to erase and then do it smaller.
> Delilah (to me): Look at what I did.
> The others look too and Barbara comments: Look how good Delilah's is!
> Jesus has erased what he had in order to start again and now he has accidentally filled in the whole screen using the fill command. Belle keeps looking at Barbara's drawing for guidance.
> Barbara: No, now this is too little.
> Stuart continues to work on his tree which is quite detailed and has a bird's nest in it
> Belle to Barbara (pointing at her prairie dog town): Why do you have more brown here? Why is your line so thick?
> Barbara: I like it that way. Now I'm going to make my cactus. (field notes 2/10)

**Figure 2 - Delilia's prairie dog town**

It is worth noting that in the above conversation, the students' concerns did not focus on the science content, but rather on the appearance of their models. The emphasis was on appearance, spatial relations and on how to manipulate the program to do what the students wished. When students talked about their models on their own, they often surprised us by focusing on aspects other than what we saw as the key considerations of making a model. Thus, in the above example the focus was on the size, color and detail of the backgrounds, rather than on how the background would be used to demonstrate the science content of food webs. This was fairly typical of the discourse that took place when students were at the computers creating their models. However, this discourse changed once the models had been finished. Talk about completed models tended to focus on what the models were showing rather than on how they were constructed.

Within the classroom context, Teresa played a role in developing the language of instruction through her whole-class debriefing sessions after they had been working in small groups on pre-modeling activities.

> Teresa calls the students back from their small groups where they have been working on their candy box models. Several groups are reluctant to come because they are not done decorating their boxes. (original conversation in Spanish)
> Teresa: I'm glad you all are putting so much effort into decorating your boxes, but I want to talk about what you are doing. Why are we decorating candy boxes?
> Jesus: We are trying to make a box that uses less wrapping material than the boxes we looked at.
> Teresa: Good. that's what we were supposed to be doing, but is that what you were doing? One group was using nine pieces of paper to decorate their box. If one box is using 9 pieces of paper to cover it, how many pieces will it take to cover 10 boxes? (Teresa waits but no one answers) How about if we had two boxes, how many pieces of paper would we need?
> Student: 18.
> Teresa: Good, how about if we had 3 boxes?
> Student: (after a long pause) 27 pieces of paper.
> Teresa: So do we readily need to use 9 sheets of paper for each box?

Students: (in chorus) No! (field notes 3/10)

Whole group discussion lead by one of the researchers was another instructional context used to introduce new kinds of activities. While periodic instruction in whole group sessions was valuable to get students thinking about a new activity or to refocus them on why they were doing what they had been doing, we also found that our normal conceptions of instruction had to change when so much of the students' work was done using computers. What we had to do to prepare students to make successful models differed in some ways from what we would have done to prepare them for other types of projects. Ample one-on-one interaction between students and adults was necessary for students to fully benefit from the project. These one-on-one interactions occurred both in the classroom setting and in the computer lab, and immerged as an important factor in our language of instruction. However, the difference between the two settings was that in the classroom, the talk was generally about planning aspects of the models that were related to science content, whereas in the computer lab the clarification was generally related to how to do a specific task on the computer, and therefore, focused on computer content rather than science content. These two types of interactions can be seen in the following quotes.

> Throughout the class period, students often came up to me to get clarification about the science content of their stories, even though they were supposed to check with other students in their group first. Generally, their questions had to do with the steps in the recycling process, such as what happens in the flotation tanks, and why the plastic is turned into pellets rather than being turned directly back into bottles or containers. Even though it was officially Spanish day, some of these discussions were in Spanish and some were in English. I tried to provide some guidance while also encouraging students to go back to their groups and raise their questions there as well. (field notes 3/31)

> Delilah added her dinosaur stamp in the middle of the screen so that it was floating in the air, and then dragged the stamp to the ground. She had about 30 frames of dragging the dinosaur to the ground and she knew that she didn't want her movie to show this. She came to me and asked me what to do, and I asked her if she had ever cut frames before. She said no so I walked her through the steps. She opened up the frame view and I showed her that by holding down the apple key and typing x, unwanted frames could be erased. She sat down and erased all the frames that had the dinosaur in the air. (field notes 4/9)

The kind of one-on-one tutoring described in these passages was significant in the students' development of the ability to talk about their understanding of both the science concepts and the modeling process. Because our project allowed for the presence of several more adults working with students than is possible in the usual classroom setting, we were able to take particular advantage of this context.

In summary, the contexts in which the language of instruction were created fall into two basic categories, those that took place in the classroom and those that took place in the computer lab. Within the classroom setting there were distinctions between whole class discussions, small group activities and one-on-one instruction, and also distinctions between topics and activities focusing on science content and those focusing on model building. Within the computer lab setting, the two most common contexts were peer

interactions among students as they constructed their models and one-on-one tutoring with a researcher helping a student fix a particular problem with his or her model. These different contexts can be directly linked to certain actions that took place in response to the language of instruction.

**Actions Taken in Response to the Language of Instruction**

Students engaged in a number of actions that indicated their growth and development both in terms of science content learning and the use of modeling as a way to aid in the expression of that l rning. For example, as students became more proficient at designing their own models, they also learned to talk about their models to others. Students had to discuss their models at the end of each unit, when we gave students a chance to present their model to a group of their peers in a show-and-tell format. There were two goals for these show-and-tells. First, they provided a chance for the model creator to talk science by describing what his or her model showed. Second, they were meant to give everyone the opportunity to practice critiquing other students' models and discussing ways in which a model could be revised so that it better expressed the science story that the designer was trying to tell.

We found, however, that while these show-and-tells did fulfill the goal of getting students to talk about their models in safe context, students were much more hesitant to critique other students' models than they were to criticize their own. Perhaps because of Teresa's emphasis on building community and teaching students to respect one another, students seemed to feel compelled to compliment the designer and tell what they liked about the model, rather than talking about how it could be improved. So, for example, the following frame from Josue's model of seed transport shows a common problem in many of the students' early models -- objects floating in the air. However, as the excerpt shows, during the show-and-tell portion of the activity, none of the students in Josue's group mentioned the floating bear as something that could be improved.

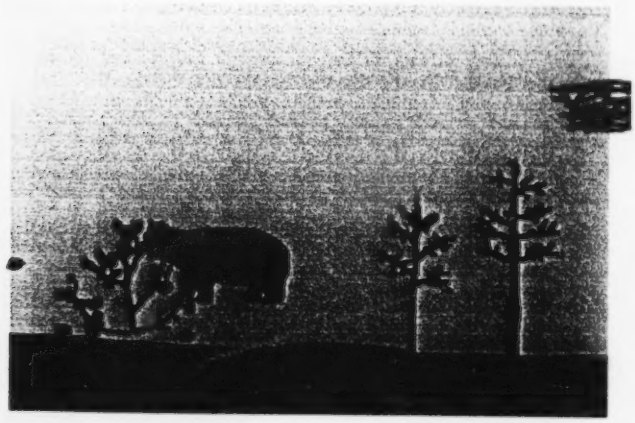

**Figure 3 - Josue's floating bear**

Josue: So my movie shows how the bear comes and eats the plums and then later the seeds come out when he goes to the bathroom, and then a new plum tree grows.
Erika: I like how the rain came down and watered the seeds before the new plum tree grew.
Donaldo: I liked it when the plums disappeared when the bear ate them.
Belle: I think your movie was very good Josue.
Cory: So how could Josue revise his model? What would make it better?
Erika: I think it's good, I like it how it is.
Belle: Maybe you could make it rain a little more. (field notes 10/20)

Throughout the project, one of our goals was to try to get students to add more detail to their science stories. We found that by the time students had completed all of the pre-modeling and model building activities in a given unit, they were generally able to explain the relevant science content in some detail. However, many students did not give detailed descriptions spontaneously. Instead, they frequently needed adult prompting before they would give full explanations of what they knew. The following example demonstrates this in the case of the Science Museum display.

One of Teresa's main roles when visitors came in the classroom on the evening of the Science Museum was to prompt the visitors to ask questions and to prompt her students to explain in detail what it was that they had made and what they had learned. I also tried to prompt students to share more information about their models by asking probing questions to the students such as: what else does "X" eat; what parts of your model came out the best? What parts would you do over again if you had another chance?
For example, when Mario came in with his brother, I asked him: So, what does your model show? What did you think about the size of the frog? Is it OK? Is it too big compared to the snake? Mario was able to answer these questions at length, but had very little to say unless he was prompted.
An adult friend of Lina's asked her a number of questions.
Daisy: So show me which part of the mural you did.
Lina: I did this whole one.
Daisy: This entire one?
Lina: Yes, and all the coyotes.
Daisy: So, what can you tell me about coyotes?
Lina looks at the report on the wall, and after several seconds, responds that they are nocturnal.
D: What does nocturnal mean?
Lina: That they go out to hunt at night. (Lina then goes on to talk about how because they are nocturnal this effects both what they eat and what eats them).
Daisy: Well, thanks for teaching me something new about coyotes.
(field notes 2/26)

Another action that became common as students' familiarity with the modeling process increased was one student showing another how to do a task on computer. This was often done without adult prompting, but rather, in response to a student's exclamations of frustration. Looking at what a neighbor was doing also served as a way in which students negotiated the meaning and the goals of their tasks. At other times, researchers had to remind students of how to do certain tasks.

Felicia: I can't do a straight line! (She is frustrated after several attempts to freehand a straight line)

Daniel: I know how to do a straight line. (Gets up and goes over to Felicia's computer). Click on this (the line tool) and then do it.
Felicia does this and is much happier with the results. Daniel goes back to his computer.
Ricardo: I need to start again. I ran out of space to draw.
Cory (to Ricardo): Is most of your picture going to be below ground or above ground?
Ricardo: Above ground.
Page: What about if you use squish? Page reminds Ricardo how to do this and it works, allowing Ricardo to create more space where he needs it and averting his having to start over.
Ricardo: Great, now I can make my holes! (field notes 2/10)

In conclusion, several specific types of actions arose from our creation of this language of science instruction. Perhaps most important were the pre-modeling activities that we found to be essential if young students were to be expected to create meaningful models at the computer. While these pre-modeling activities generally lead to reasonably successful models, we were never as successful in getting students to take actions to further improve their models through revision. Nor did students' models tend to reflect the same degree of complexity that they expressed in telling their science stories orally. We also found that actions differed significantly between the classroom setting and the computer lab setting, based on factors such as the complexity of the task, the amount of direction, and the opportunity to work collaboratively. Finally, I turn to some of the consequences of these actions.

## Consequences of the Actions Taken

Many of the actions that students took in the process of creating their models resulted from the language of instruction that we developed in this classroom over time. In turn, these actions had consequences for how students came to conceive of both science and modeling making. One example of this is that, over time, students came to tell science stories based on their own experiences. While at the start of the project, students did not tend to relate science to their own lives, by the end, many seemed to do this naturally, as the following excerpt indicates:

Teresa is talking about how nature recycles its own waste, and Donaldo raises his hand and tells a story of finding a dead bird on the ground and how he put it in a plastic bag with some sand and water and took it home.
Bart: He should put it on the ground so that it can decompose back into the soil.
Donaldo: I put sand in it and grass and a little water.
Johnny: I did the same thing when I found a dead bird, only I didn't put it in a plastic bag. I was walking and my sister found a dead bird and I put it under a rock.
Julia: I think Donaldo should put it back on the ground.
Bart: At my friend's house they have this skylight thing and they had to paint a picture of a hawk on it to keep the birds from flying into it, but sometimes they still do and they go splat, and then we bury them.
Ryan: My dad found a dead bird and he picked all the feathers off and left the bird on the ground.
Teresa: So Donaldo, now what do you think you should do with the bird you found?
Donaldo: I should take it out of the bag and put it back in the ground.
Teresa: Why?
Donaldo: So it can decompose and help the plants grow.

Teresa: Super, Donaldo, I think that's what you should do too.
(field notes 3/11)

This example clearly shows how students were learning to think about science in terms of their own experiences in the world around them and then link those experiences back to the science content that they were learning in class. Getting students to connect with and talk about science in meaningful ways was one of the primary goals of our project, and we all found examples of this kind to be extremely encouraging. However, for Teresa, while she was quite pleased with the science learning that was taking place, she also saw a certain cost to the implementation of our instructional approach. This cost had to do with the flexibility that she had in letting the students' interests lead her choice of science content. By participating in our project, she basically agreed to trade off greater depth of coverage of topics in exchange for less spontaneity in her teaching. Thus, one consequence of our language of instruction was that it placed certain constraints on how science could be taught. These constraints were directly related to the kind of background that we found students needed on a given subject before they were able to construct a successful model that reflected some understanding of that topic. However, even when students had a grasp on the science content in question, there was still the additional layer of mastering the modeling software in order to create a successful representation.

Our time in the computer lab generally focused on working with students on the nuts and bolts of how to make the program do what they wanted it to, rather than on our primary goal of having students work with models in order to expand their understanding of science concepts. Whether students talked about their computer models in terms of the science content that the model demonstrated or in terms of the model making process itself was largely a function of the setting.

To facilitate students' talk about science content through the medium of their models, we eventually shifted from an emphasis on causal mechanisms underlying science processes to an emphasis on how processes occur in time and space. Still, we had to constantly remind students that their computer modeling activities (both the actual work with the computers and the pre-modeling activities that took place in the classroom) were connected to the other science activities they were doing with Teresa. One of the consequences of our actions, then, was getting students to consider the story they were telling with their model in light of the relevant science content.

Oscar (to Donaldo): Look at this beaver. Look at this beaver.
Oscar is looking in the stamps folder and finds a beaver that was one of the drawing that originally came with the program. It is an anthropomorphized beaver juggling balls, and Both Page and I tried to convince him that it is not a good stamp to use in his model both because it is not really what a beaver does and because there are no beavers in the plains that Oscar is studying.
Page goes over to help Donaldo who has not made much progress.
Page: Tell me what your movie is going to show?
Donaldo: An eagle.
Page: What does the eagle eat?
Donaldo: Mice.
Page: What do the mice eat?
Donaldo: Cheese.

Page: Do you think that mice that live in the desert eat cheese? Is there cheese in the desert? Think about what we have been talking about with food webs.
Donaldo: Flowers, then.
Page: OK, then you need to draw some flowers.
(field notes 2/28)

**Figure 4 - Oscar's anthropomorphized juggling beavers**

This example clearly shows how discourse played a central role in getting students to connect the models they were making with the science content that they were studying. Because we knew this kind of discourse was important, we worked a great deal on getting the students to talk about and explain the science concepts they were learning to others. However, we found that there were substantial differences in students' willingness to talk about their understanding based on the audience that they were talking to. In some cases students gave an accurate picture of what they knew about the topic, but in other cases, they did not demonstrate what we knew that they understood.

Teresa's students were all involved in the activities that were going on in the Science Museum, but some spoke more than others. Fatima told me before class that she was excited to show her model to other students but when the older kids came in and wanted to see it she got very quiet and wouldn't explain what her model showed. She would only speak to me and only in Spanish, and she would not address the older kids directly. Later, she told me that she didn't want to show her model because of the one part where the elk gets squished by accident. There was a clear difference in how the students acted when the first group (5th graders) was visiting and when the other two groups (another 2nd grade and a 1st grade class) were visiting. With the older kids, Teresa's students were much quieter and less willing to explain things. Most of them just stood around and didn't say much, while others talked among themselves and avoided talking to the 5th graders. With the younger children however, there was much more discussion of the projects, what they were supposed to show, how they had been done, etc. (field notes 2/26)

Thus, finding the right audience to allow students to express what they have learned was critical for getting students to engage in meaningful discourse about science. While we believed that Science Museum was the ideal setting for this discourse, we found that even then, other factors, such as the specific audience, influenced the effectiveness of the



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setting. Another factor related to audience had to do with the way in which students code switched when explaining or writing about the science concepts in the context of their model creation. The following two passages clearly demonstrate this.

> Delilah decided to write in Spanish, but always talked to me in English. We talked about the plastic recycling machine, and specifically about the filtering process and the floatation tanks, but when Delilah went to write about this, she realized that she didn't have the Spanish vocabulary for these items. Likewise, Julia asked me in English about where plastic bottles were made in the first place but had trouble summarizing our English conversation in Spanish in her paper. No native English speakers had this problem since none of them were writing in Spanish or speaking in Spanish about the science content – they did not have to code switch. (field notes 3/11)

> Knowing that Kim is a native Spanish speaker, I asked her in Spanish what language she'd prefer to speak during her interview, and she said "Spanish" in English. So, I asked her the first few questions in Spanish, but she always answered in English. I started to ask her the next question in English, and she went blank and asked me to ask the questions in Spanish. I continued to ask the questions in Spanish, and she continued to respond in English – a strange example of code switching. (field notes 2/27)

Two tendencies of English language acquisition can be seen in these passages. The first is that acquisition is not always even between comprehension and production. Thus, when Kim was able to fully comprehend the questions being asked (in Spanish) she was able to answer in either language and chose to answer in her second language (English). However, when the question was posed in her second language, she did not fully comprehend it and, therefore, could not answer in either language. This example runs counter to the generally accepted, but oversimplified, notion that comprehension precedes production in the second language. The second point is that when learning technical vocabulary and concepts in the second language (such as Delilah and Julia discussing the recycling process with me in English), students often find that they do not have the necessary vocabulary in their first language to write or talk about these concepts successfully. This may then force them back into their second language.

In summary, the consequences of the language of science instruction we developed can be seen in terms of processes and situations that both helped and hindered students attempts to engage in the discourse of science. Factors that aided in the acquisition of this discourse included: 1) classroom discussions and activities aimed at helping student connect science to their own personal experiences; 2) greater depth of coverage of science topics; 3) the creation of settings such as the Science Museum and the show-and-tell sessions that encouraged students to talk about the science content demonstrated in their models; and 4) settings that forced students to deal with issues of first language-second language code switching in the discourse of science. Factors that hindered students' acquisition of the discourse of science included: 1) frustration that arose from the difficulty of mastering the nuances of the computer software; 2) the frequent need to focus on the "how to's" of model construction rather than on the science content being modeled when at the computers; and 3) the presence of some audiences that were not receptive to leaning science content from the students. In the final section, I now turn to the implications of this study for teaching science to primary grade students in diverse settings.

**Discussion and Implications**

I have explored the development of our concept of the language of science instruction in terms of the five-faceted sociological paradigm of causal conditions, properties of the phenomenon, the contexts in which it occurs, actions used in response to the phenomenon, and consequences of those actions. Using this perspective, I have come to believe in the importance of five factors that were relevant to students' success in learning to think, act and talk science in this setting. The first factor was students coming to view science as a discourse in which they were personally willing and able to engage in an active manner. When students shared their models in both the show-and-tell sessions and during the Science Museum, they were demonstrating their ability to engage in science discourse. The second factor was students coming to understand the value and relevance of their own personal experience as a legitimate part of their understanding of science concepts. We found that the whole class discussions with Teresa provided students with opportunities to see the connections between their own experiences in the natural world and their understanding of science.

The third factor we found to be important to the success of our language of science instruction was the development of students' willingness to engage in content-related interactions with both peers and adults. Many of the pre-modeling activities that students undertook while conceptualizing the science stories that they wished to tell with their models required students to ask questions, give advice, and collaboratively construct meaning with peers, researchers and the classroom teacher. The chocolate box model stands out as an example of this. The fourth factor involved students learning to consider social applications of science. In our choice of topics we tried to emphasis the value of science as a way of addressing social problems. These issues sparked the interest of students, and the success of the final unit on recycling can be seen as an outcome of this.

The fifth and final factor that was central to our language of science instruction was the way in which students played an active role in helping the adults tailor activities to each individual's needs and abilities. Unlike the other computer-based research projects discussed in the beginning of this paper, our language of instruction was not something constructed by the researchers and then imposed on the students (and teacher). Rather, it was created collaboratively over time as students' desires and needs helped shape the instructional content and approach. Thus, while these five factors may seem to some to be obvious, the key is that they were actually adopted and acted upon by the 2nd and 3rd grade students, rather than just being ideals that the teacher or researcher hoped to instill.

There are several implications for this study. As mentioned earlier, the study pushed the boundaries of the previous research on using computers as tools for aiding in students' conceptual understanding of science in two ways: first, by pushing the question of appropriate use of computers for science learning down to the primary elementary grades, and second, by focusing on the role of the discourse of school science as a necessary condition for students' proving mastery of science concepts.

In terms of the first issue, I believe that we have shown that using computer models with 2nd and 3rd graders can be beneficial to their developing abilities to think, act and talk in ways that are compatible with the culture of school science. However, this is only true when a great deal of support, both technical and pedagogical, is provided. In terms of technical support, the presence of multiple researchers with substantial experience in both curriculum development and computer programming, allowed for the design of both pre-modeling and modeling activities which may not have been possible for Teresa to develop. Also, this gave students access to a level of coaching and individualized attention that would not otherwise have been possible. Similarly, in terms of pedagogical support, as researchers, we had the luxury of spending a great deal of time designing materials for use in the class that would not have been possible for a classroom teacher. Also, simply by adding several adults to the room, we were able to monitor and support group work and one-on-one interactions in ways that would not otherwise have been possible. Together, these factors allowed us to develop the complexity of interactions that resulted in the degree of success we were able to achieve.

Additionally, even with all of this support we were not always satisfied with what many of the students were able to produce, even when we replaced the more difficult simulation software with the less demanding animation software. For example, the models students created generally did not demonstrate a degree of complexity equal to what the students actually knew about the topic. Also, we engaged students in so many activities and discussions that they seemed to have a hard time keeping all the ideas in their heads. As the units progressed, they seemed to learn new things but forgot some of the prior concepts that they had known. Thus, models often disproportionately reflected the last topic that was addressed in pre-modeling activities, even when that topic was not the central issue. The recycling models were a prime example of this. In short, even in an idealized learning environment, 2nd and 3rd graders are pushed to their limits when asked to develop computer models and use those models as vehicles for thinking, acting and talking in ways that reflect the culture of school science.

I can discuss the second implication, focusing on the role of the discourse of school science as a necessary condition for students to prove mastery of science concepts, by comparing some of my claims to the claims of White and Frederiksen. In our work on model building with significantly younger students, I found some areas of consistency but also significant differences with the work of White and Frederiksen. First, it should be noted that after two years of working with Intermediate Causal Models with our students, we concluded that the vast majority of these young students were not cognitively able to design and create simulations of this kind, and we switched instead to animation-based models that are incapable of modeling causal mechanisms. While it is probably true that the use of ICM's is significant when the focus of teaching modeling is to teach problem solving, we concluded that both inquiry skills and the discourse of science can be adequately taught using animations rather than simulations. That said, in considering White and Frederiksen's four instructional ramifications, my data seem to support two of their claims and provide contrary evidence for the other two, in the case of lower grade elementary students of culturally and linguistically diverse background.

Our findings do not support White and Frederiksen's claim for the value of using semi-abstract representations in student models. Instead, we found that our students were better able to make use of concrete representations from their own personal experience as tools for problem solving. I do find evidence to support White and Frederiksen's second ramification, namely, the importance of teaching modeling, not just models. Having students create their own models, through the process of design, creation and revision activities was valuable to students both in their development of problem-solving skills and in the opportunities it provided for students to think, act and talk like scientists.

I concur with White and Frederiksen's third claim regarding the value of teaching problem solving in terms of model-based reasoning. However, this kind of reasoning was obviously more limited in our project since our use of animations did not provide the same opportunities to reason from the behaviors of a model to a scientific principle, as would be the case for simulation models. Finally, while I acknowledge the obvious role of cognitive and metacognitive skills in leaning to design and create computer models, in our setting, successful model creation can be attributed more to the development of students' science stories through group activities, and the refinement of these stories through peer interactions and discussions both during pre-modeling activities and while actually creating the models at the computers. In other words, I see model building in this context as more of a social process than an individual cognitive task.

Thus, even for primary grade elementary students with limited prior exposure to computers, the use of student-generated computer models, in conjunction with the construction of physical models and other hands-on activities can provide meaningful opportunities for students to learn to think, act and talk in accordance with the rules for success in school science settings. Additionally, the creation of a modeling environment of this kind can provide an effective strategy for mediating the difficulties that English Language Learners often have with mastering the academic discourse of science. To this end, I hope we have helped to address Lee and Fradd's (1998) call for studies providing some insights into how successful bilingual classrooms establish instructional congruence in science learning and language development. Additionally, I believe that the process by which students go about learning to create computer-based models provides a context to help generate and clarify the rules of scientific discourse called for in the National Science Education Standards (National Research Council, 1996). Further studies using student-generated computer models or other kinds of models to expand students' opportunities to engage in the discourse of school science may provide still more clarification of these issues.

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